AD-A052 765 ARMY MATERIALS AND MECHANICS RESEARCH CENTER WATERTO--ETC F/G 11/6
TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE.(U)
FEB 78 K H ABBOTT
UNCLASSIFIED AMMRC-MS-78-2 NL

1 OF 1
AD
A052765

END
DATE
FILMED
5-78
DDC

AMMRC MS 78-2

AD

TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE

KENNETH H. ABBOTT
MATERIALS DEVELOPMENT LABORATORY

February 1978

Approved for public release; distribution unlimited.

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
14 AMMRC-MS-78-2 ✓

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE,

5. TYPE OF REPORT & PERIOD COVERED
9 Final Report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 Kenneth H. Abbott

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Army Materials and Mechanics Research Center ✓
Watertown, Massachusetts 02172
DRXMR-E

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
D/A Project:
AMCMS Code:
Agency Accession:

11. CONTROLLING OFFICE NAME AND ADDRESS
U. S. Army Materiel Development and Readiness Command, Alexandria, Virginia 22333

12. REPORT DATE
11 February 1978

13. NUMBER OF PAGES
13 12 16P.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

TRIP steels
High strength steels
Alloying
Physical properties
Mechanical properties

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE JOB

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403 105 —

Block No. 20

CONTENTS

INTRODUCTION

Since World War II, a large number of technological improvements have been introduced and utilized by the steel industry of the United States. Some of these are: vacuum arc remelting, use of the oxygen lance, new high strength alloys, ausforming, control of thermal gradients during ingot solidifications, and electroslag remelting. Each has contributed to the evolution of ultrahigh strength, high quality steels. During World War II, maximum yield strengths in steels used in high performance structures such as guns, tanks, and aircraft landing struts were on the order of 90,000 to 150,000 psi. Today, premium quality steels are used in the yield strength range of 180,000 to 280,000 psi for such applications. Metallurgical processing and heat treating practices developed during and subsequent to the war, insure that optimal microstructures are obtained so that the best ductility and toughness possible are achieved at these strength levels.

Unfortunately, as steel strength levels have increased, ductility has decreased. World War II high quality steels had ductilities as determined by tensile elongation measurements of 30 to 40% at the 100,000 to 150,000 psi strength levels. Current high quality steels in the 180,000 to 280,000 psi strength range have tensile elongations of 15% or less. While usable steel strength levels have doubled since World War II, the amount of deformation which a high strength steel can tolerate prior to fracture has decreased by about a factor of two. This loss of ductility makes more critical such small metallurgical defects as inclusions and such small mechanical defects as machine tool marks, since the stress concentrations which they cause cannot be relieved very much by limited localized plastic flow. Therefore, cracks are more prone to originate from defects in today's high strength steels than from those in World War II steels. Furthermore, cracks, once originated, propagate more easily in a steel of low ductility than in a steel of high ductility.

During World War II, occasional catastrophic brittle fractures occurred in gun barrels and other high strength steel components. Such brittle fractures were more common at low ambient temperatures than at high ambient temperatures since steels become less ductile as temperature decreases. Research into the nature of these fracture problems led to control of the steel microstructure through heat treatment to minimize risk of brittle fractures. Increases in ductility (or toughness, when Charpy rather than tension tests were used) at the same steel strength level resulted from the microstructure control. Appropriate quality assurance procedures were incorporated into the steel specifications, and brittle fracture problems diminished substantially. (Some still remained due to technical negligence in design or materials selection.) Now that strength levels have been increased at the expense of ductility, the occurrence of brittle fractures in high strength steel structures is expected to increase. These increases in steel component fractures are expected in spite of the fact that design procedures have become more sophisticated. Design equations do not contain parameters which permit crack growth prediction and, thus, do not guard adequately against the risk of brittle fracture.

There are increasing numbers of military applications where ultrahigh strength steels are needed. Usually, steel strength increases are desired to permit reductions in weight so that either a performance increase or a logistic

benefit is obtained. However, there are cases where new ideas or significant hardware innovations simply cannot be implemented without use of an ultrahigh strength steel. The recent laboratory discovery of TRIP steels permit, for the first time, doubling the strength of the best World War II steels without loss of (and possibly with some increase in) ductility. The nature of TRIP steels, their current status, near term benefits, and future potential are the subject of this report.

During the late 1960's Zackay et al.[1] at the University of California developed TRIP steels. They selected steel compositions such that the temperatures (M_s) at which austenite would transform isothermally to martensite were well below room temperature. At the same time, the highest temperature at which austenite transforms to martensite by straining (M_d) is above room temperature.

TYPICAL COMPOSITIONS AND PROPERTIES

TRIP steels are stainless steels having total alloy contents of 20 to 30 weight percent and 0.25 to 0.35 carbon levels[2] as indicated in Table 1. Note that combined nickel-chromium content of A steels is about 17%, and the nickel content of B steels is 22% to 24%. Such steels are much more expensive than medium carbon lean alloy steels which are capable of heat treatment to similar strength levels. In addition, both nickel and chromium are strategic and critical materials since 100% of chromium must be imported into the United States and 75% of nickel must be imported.[3] Zackay has expressed hope that manganese may be substituted for nickel in the type A steels, and this may permit use of the thermal cycling process.* However, this will not help the strategic alloy situation since 95% of manganese also must be imported into the United States.[3]

Table 1. SOME TRIP STEEL COMPOSITIONS (WEIGHT PERCENT)

Alloy Type	Cr	Ni	Mo	Mn	Si	W	Co	C	Ref.
A	9	8	4	2	2	-	-	0.30	1
	9	7.5	4	2	2	-	-	0.25	1
	9	8	4	1	2	-	-	0.25	1
	9	8	2	0.5	2	-	-	0.25	2
	9	8	-	0.5	2	2	-	0.25	2
	9	8	4	0.5	0.5	-	3	0.25	2
B	-	24	4	-	-	-	-	0.25	1
	-	24	4	-	-	-	-	0.36	2
	-	24	4	0.2	0.2	-	-	0.30	2
	-	22	4	1.5	-	-	-	0.25	1

The M_s and M_d temperatures in TRIP steels are very dependent on the steel composition, and the type of TRIP processing which is used depends on the location of M_s and M_d temperatures.[1] If thermal cycling is used, then the M_s temperature of reverted austenite must also be considered, and it, too, is strongly dependent on composition.[2] The properties obtained after processing are strongly dependent on both composition and process detail. In fact, the TRIP process takes place only

1. ZACKAY, V. F., PARKER, E. R., FAHR, D., and BUSCH, R. *The Enhancement of Ductility in High Strength Steels.* ASM Transactions Quarterly, v. 60, June 1967, p. 252.
2. KOPPENAAL, T. J. *Research in Development of Improved TRIP Steels.* Philco-Ford Corp., Newport Beach, California, Contract DAAG46-72-C-0047, Final Report, AMMRC CTR 73-4, January 1973.
3. *Materials Needs and the Environment Today and Tomorrow.* Chapter 2, Final Report of the National Commission on Materials Policy, June 1973.

*Technical conference on TRIP steels held at Army Materials and Mechanics Research Center on 27-28 June 1974.

when the steel composition and processing conditions have been selected to produce the fine carbide dispersion in metastable austenite.

As the title of Zackay's paper implies,[1] the real benefit of the TRIP process is that tensile ductility at high strength levels is considerably greater than for heat-treated or ausformed alloy steels. In terms of tensile elongation the type of improvement possible is illustrated in Figure 1. Note that at equal strength levels, TRIP steels can have 2 to 3 times the tensile elongation of the *best* low-alloy high strength steels. In general, tensile ductility is enhanced by up to a factor of 3 at 100,000 psi yield strength, and by up to a factor of 2 at 300,000 psi yield strength. For yield strength levels below 225,000 psi, either austenitic of austenitic plus martensite structures provide the enhanced ductility; but attainment of higher strengths requires the mixed microstructure. The data in Figure 1 represents considerable scatter which reinforces the strong dependence of properties on composition and processing variables.

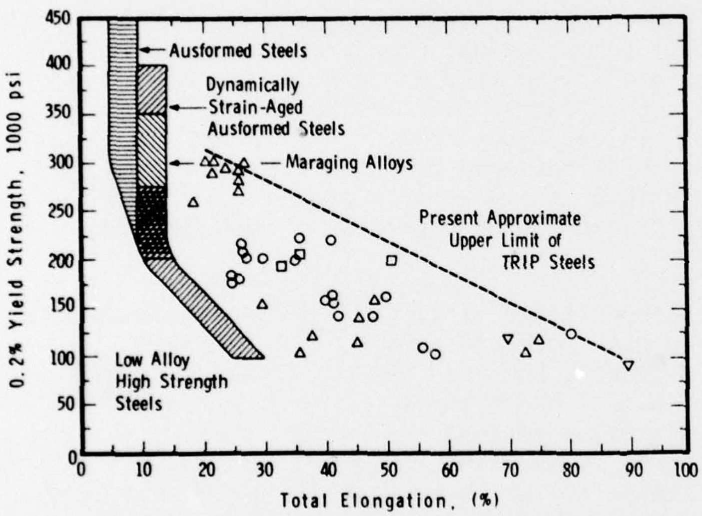

Figure 1. The ranges of the 0.2 percent yield strength and the total elongation at failure (from room-temperature tension tests) that are characteristic of various classes of high-strength steels. The shaded areas represent scatter of data. (Ref. 1)

The fatigue properties of TRIP steels have been studied by several investigators.[4-10] Some found that TRIP steels had lower fatigue properties than conventional high strength steels,[4] and some found higher fatigue crack growth resistance in TRIP steels.[5] It was believed that this discrepancy was related to processing variations which produced changes in austenite metastability. This was confirmed,[6] and it was shown that "the greater the instability of the austenite,

4. LAL, D. N., BLOCK, U., and WEISS, V. *Mechanical Behavior and Transformation Characteristics of TRIP Steels.* Proceedings of the Third International Conference on Fracture, Munich, Germany, 1973.
5. GERBERICH, W. W. *Metastable Austenitic Steels with Ultra-High Strength and Toughness.* SAE Paper No. 690262, International Automotive Engineering Congress, Detroit, Michigan, 1969.
6. WEISS, V., et al. *The Relationships Between the Transformation Characteristics and the Fatigue Properties of TRIP Steels.* Syracuse University, Syracuse New York, Contract DAAG46-72-C-0177, Final Report, AMMRC CTR 73-50, December 1973.
7. GERBERICH, W. W., HEMMINGS, P. L., ZACKAY, V. F., and PARKER, E. R. *Interactions Between Crack Growth and Strain-Induced Transformation.* Livermore Research Laboratory, LRL Report 18467, September 1968.
8. WEINSTEIN, D. *Design Properties of TRIP Steel.* Report on Stanford Research Institute Project No. 7722, December 1969.
9. AZRIN, M., GAGNE, R. A., HOLMES, K. D., QUIGLEY, F. C., and SHEPARD, L. A. *Development of TRIP Steels for Army Applications.* Army Materials and Mechanics Research Center, AMMRC TR 71-57, December 1971.
10. CHANANI, G. R., ANTOLOVICH, S. D., and GERBERICH, W. W. *Fatigue Crack Propagation in TRIP Steels.* Met. Trans, v. 3, October 1972, p. 2661-2672.

the larger is the volume of martensite formed and the greater is the fatigue crack growth resistance." Discussions on the subject of fatigue produced unanimity of opinion and point up the necessity of obtaining high austenite instability in TRIP steels for applications where fatigue resistance is needed.

TRIP steels have been shown to exhibit high K_c values, particularly at room temperature.[5,6] Zackay reported[1] that properly processed TRIP steels have high K_c values, and that these values are reduced very little as section thickness increases. Fracture toughness does decrease with test temperature,[6] and may reach fairly low values at liquid nitrogen temperatures. However, for service applications in the ambient environment, fracture toughness of TRIP steels is considered to be high.

Because of the high percentages of nickel (and chromium) in TRIP steels, corrosion resistance is comparable to that of commercial stainless steels.[2] Stress corrosion cracking resistance of TRIP steels is also expected to be comparable to that of stainless steels. However, TRIP steels have been shown[10,11] to be strain rate sensitive. It was reported[11] that ductility decreases with increasing strain rate to about half of its quasi-static value. Thus, fracture properties of TRIP steels which depend on ductility for their high values would be expected to decrease with increasing strain rate. Quantitative information is needed to define these strain rate effects since many military components are subjected in service to dynamic loads. Additionally, as may be inferred from the TRIP process details, the mechanical property anisotropy in TRIP steels is very pronounced. However, it is recognized that anisotropy may be beneficial depending on the specific application.

Both types of TRIP steels have properties of interest for Army exploitation. The type A steels can be processed to high strength (280,000 psi Y.S.) only by thermomechanical treatments. Type B steels, however, can be processed to strength (160,000 psi Y.S.) by heat treatment alone. Both types have high ductility and fracture resistance, particularly in the low ambient temperature range of Army concern, i.e., room temperature down to -40 F, as illustrated schematically in Figure 2. Because of the ductile-brittle transition which many steels undergo in this temperature range, service component failures are most likely when the first stress

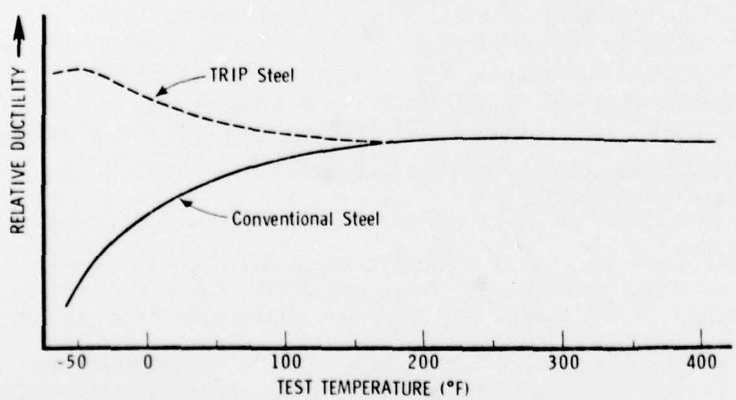

Figure 2. Schematic of relative fracture resistance of high strength steels at low ambient and moderately elevated temperatures.

11. AZRIN, M., OLSON, G. B., and GAGNE, R. A. *Inhomogeneous Deformation and Strain Rate Effects in High Strength TRIP Steels.* Army Materials and Mechanics Research Center, AMMRC TR 73-12, March 1973.

is applied in cold weather prior to warm up of the component. TRIP steels would not be prone to such service failures because the ductile-brittle transition occurs at lower temperatures.

POSSIBLE ARMY APPLICATIONS

The thermal cycling process for TRIP steels of the B type permits immediate exploitation of these steels in Army applications. At B type TRIP strength levels (160,000 psi Y.S.), several commercial steels have adequate fracture resistance for Army use at low ambient temperatures, but none have the very high ductility of the TRIP steels. Applications, therefore, would be confined to those where very ductile behavior is essential. Two such applications which have been publicized by the Aeronutronic Division of Philco-Ford are turbine burst containment rings and a fin-forming projectile.[12] For each of these applications, no other steel had sufficient ductility at the strength level required.

Until composition modifications to the type A TRIP steels permit hardening by thermal cycling, these steels must be hardened by thermomechanical treatments. The necessity of warm working metastable austenite severely limits the sizes and shapes which can be processed to 280,000 psi Y.S. and high ductility. The following discussion is based on use of type A TRIP steels which are thermomechanically processed, and is divided according to commercial shapes. Subsequent development of thermally cycled type A alloys to 280,000 psi Y.S. would permit immediate exploitation in all commercial sizes and shapes.

Plate and Strip Shapes

Warm rolling of austenite in the temperature range of 800 to 900 F produces very large separating forces on roll mills. This increases risk of roll breakage compared to hot rolling, and steel mills will not take such a risk with their production rolling equipment. Production of TRIP steel flat stock is restricted to strip mill production in widths of about six inches where roll separating forces in strip mills are tolerable.

Strip shapes can be made on several commercial rolling mills. Following rolling, TRIP steel is in the hardened condition and difficult to form into shapes. It can be heated up to perhaps 800 to 900 F to facilitate forming, but higher temperatures would significantly reduce the strength-toughness advantage of the TRIP process. Unfortunately, heating to these temperatures does not soften the steel appreciably so that forming does not become much easier. Thus, forming TRIP steel strip into useful shapes may well prove to be a difficult practical problem. If such forming can be accomplished without impairing the TRIP process, there are a large number of aircraft brackets and tie-down fixtures which would be more reliable if made from TRIP steel. They would be stronger for the same weight and would be less prone to brittle fracture than standard brackets in service use. The increased bracket costs would be more than offset by greatly increased reliability in service.

12. KULA, E. B., and AZRIN, M. *Thermomechanical Processing of Steel Alloys* in Advances in Deformation Processing. New York, Plenum Press, 1978, p. 245-300.

TRIP steel plate would be excellent for such applications as tank floor plates where large quantities of blast energy could be absorbed by plastic deformation without fracture. Both high strength and high ductility are needed for high energy absorption with low gross deformation to minimize air pressure rise inside the tank. However, if plate is made by welding TRIP steel strips together, no benefit would exist since the weld metal does not undergo the TRIP process and weld fractures would occur. This weld limitation is important since TRIP steel applications are essentially limited to nonwelded structures at this time.

Provided that TRIP steel strip can be rolled or shear spun to ring configurations, there is a need for its use as shrouds or containment rings on high performance turbine engines. Rotor blade fractures occur occasionally in turbines, often with catastrophic results. Because of the high speed of rotor rotation and consequent high centrifugal force, fractured rotor blade fragments have high velocities and large kinetic energies. This situation is not advisable in aircraft, nor in any other situation where adjacent equipment and personnel are subject to serious damage or injury from rotor fragment impacts. Because of their high strength and ductility, TRIP steels will be highly effective energy absorbers for this applications.

Rod and Wire Shapes

TRIP steel rod can be made on large extrusion presses, and strengths approaching 300,000 psi at 25% elongation should be achievable. Subsequent forming of complex shapes will be difficult if TRIP character is to be maintained. However, rod shapes are commonly used in many applications such as shafting, struts, and torsion bars, where only simple machining (rather than subsequent forming) operations are performed.

Rod and wire shapes are used for the manufacture of coil springs. Normally coil springs are overdesigned in the sense that the strength of the material is underutilized. Use of TRIP steels in coil springs would permit some weight reduction due to its greater strength-ductility properties (including anisotropy of mechanical properties), and, in addition, would provide an increase in reliability due to the greater resistance of TRIP steels to brittle fracture. Since the mobile Army is "suspended from springs," the number of potential applications is rather large. Incidentally, TRIP steel strip shapes would be beneficial in leaf springs just as rod and wire shapes would be useful in coil springs.

TRIP steel shafting for power drive train applications may permit some equipment weight reductions due to use of higher strength levels than those now used. However, little torsion fatigue data has been obtained on TRIP steels. Thus, the real benefits for such applications cannot yet be estimated. For the torsion bar application, TRIP steel may prove beneficial. Even if fatigue properties of TRIP steels are no better than those of commercial steels at the same strength level, use of TRIP steels at higher strengths would result in longer torsion bar life. Torsion bar fractures usually initiate at corrosion pits on the bar surface. Since TRIP steels are more corrosion resistant than currently used torsion bar steels, there is a lower probability of existence of critical crack origin sites in TRIP steels. Greater service life of torsion bars is a definite probability. The generation of materials engineering data in the torsion fatigue area is obviously needed prior to quantification of Army benefits.

For wire and cable applications, the TRIP process would provide an innovative factor of safety. Commercial steel wire at high strength levels undergoes very little elongation (10% to 15%) prior to fracture. TRIP steel wire that is accidentally overloaded, elongates and becomes stronger from the TRIP mechanism. Thus, failures due to small accidental overloads would not occur. Wire drawing die technology is believed adequate for manufacture of TRIP steel wire, and cable winding techniques are suitable for winding TRIP cable. TRIP steel wire and cable technologies should be pursued vigorously so that materials engineering data can be generated to establish specific Army benefits from use of TRIP steels in these items.

Tubular Shapes

Large capacity extrusion presses are capable of making TRIP steel tubing in sizes up to several inches in diameter provided that "thin" wall sections are involved. Machining of tubular sections can be handled readily but forming, as with rod shapes, would not presently be feasible. Extruded tubing is used in many applications such as lightweight structural members, aircraft shafting, and pressure vessels. For the structural application, joints of TRIP steel tubular sections would have to be designed with care since the TRIP mechanism would not occur in the welds. Otherwise, TRIP tubing could be employed readily, but materials engineering data would have to be obtained for a variety of combined stress states for both single and repeated (fatigue) loading before specific benefits could be predicted. Similarly, the aircraft shafting application requires data acquisition for torsional fatigue prior to prediction of TRIP steel benefit. This application, however, is considered of sufficient potential that a high priority effort should be initiated.

The pressure vessel application is one of most significant promise for TRIP steels due to the 2:1 biaxial tension stress field in tubular pressure vessels and the high tensile ductility of TRIP steels. An important military pressure vessel is a gun barrel. Barrels in rapid fire weapons often get heated above the TRIP process deformation temperature, but since all steels have adequate ductility at these high temperatures, TRIP steels are not recommended. Recoilless rifles, on the other hand, are not fired rapidly and do not overheat above the TRIP extrusion temperature. TRIP steels are a natural for this application because of the beneficial combination of lower rifle weight due to the use of a higher strength steel and increased safety due to the lower probability of premature fracture. Normally, when the strength of a steel component is increased, the risk of premature failure is also increased. However, for the recoilless rifle application, use of TRIP steel would *permit increasing steel strength* while *simultaneously reducing risk of premature failure*. This application should be investigated as a high priority engineering effort. TRIP steel should also be considered for artillery gun barrels, since all premature and catastrophic gun barrel failures occur on "first round" shots at low temperature in a cold barrel. This is precisely where TRIP steels have high fracture resistance and their benefit in increased reliability would be maximum.

There are at least two other specific applications for aircraft: pressure actuator cylinders and crash attenuators. In helicopters, hydraulic actuator cylinders are very vulnerable components. If they were made from high strength TRIP steel they could be made somewhat smaller and lighter in weight and the armor

weight required for their protection could be reduced. Tubular TRIP steel permits, for the first time, development of a high performance crash attenuation device. The extrusion attenuator works on the principle illustrated in Figure 3. For such a device, the higher the strength of the cylindrical component, the greater the energy absorption. However, all high strength steels in this application would fracture rather than extrude over the tapered mandrel. TRIP steels would transform and flow plastically while being work hardened. In a properly designed configuration, very high energy absorption without fracture would result, and a quantum jump in crash attenuation capability would be achieved. Such attenuators could be used on pilot seat mounts to increase survivability. They could also be used as accidental overload attenuators to prevent damage to the landing gear of the aircraft structure. Needless to say, these attenuators may also be used to prevent heavy equipment damage in air drop devices as well.

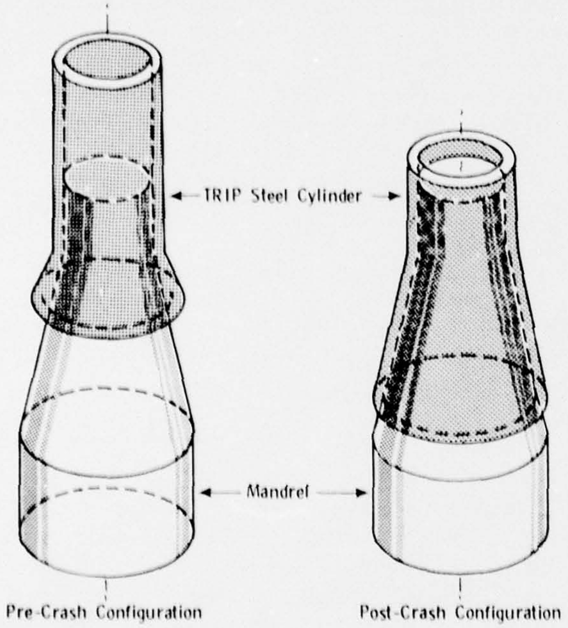

Figure 3. Crash attenuation device concept.

Forgings

TRIP steel forgings can be made, but only for simple shapes where large reductions in metal thickness can be achieved during the forging process. TRIP forging must presently be done at temperatures of 800 to 1000 F, rather than the 1900 to 2200 F normally used for steel forgings. Forces for TRIP forgings would be very high and only small forgings could be made. Obviously, development of thermal treatments to achieve the TRIP process would be required prior to extensive use of TRIP steel forgings.

SPECIFICATIONS

There are three important areas to be considered in materials specifications which govern the quality and reliability of materials. These are: (1) the composition or chemistry of the material, (2) the details of the processes by which it is produced, and (3) the resultant properties which are required for it to function

in its intended use environment. It is obvious that the third (properties) is dependent on the first two. It is also evident that if detailed requirements are specified for all three, no logical basis would exist for rejection of material lots which failed to meet the requirements. That is, if the product used the required chemistry, and the material was processed exactly as specified, the Government would be obligated to buy the material regardless of the properties obtained. For this reason, the policy followed in the preparation of materials (MIL) specifications is to specify the required properties or performance and place some controls on either the chemistry or processing details. This allows the producer latitude in selecting either chemistry or process details (the one which is not specified) in order to meet property requirements. Property measurements can then be employed conveniently for accept-reject decisions of production lots.

In practice, some additional controls are often enumerated in the specification document. For example, the specification for rolled homogeneous steel armor (MIL-S-12560) specifies both mechanical and ballistic property requirements. The mechanical properties require that the armor plates be given a water quench and temper heat treatment, since this yields a martensitic microstructure and is the only one for which the Charpy V-notch impact requirement can be achieved. The properties specified in this instance also define the general process to be used in armor manufacture but permit variation in detail. The steel chemistry is left to the discretion of the manufacturer. He is constrained only by permissible variation limits in the chemistry he selects and by limits in carbon content (for armor weldability) and phosphorus and sulfur levels (for steel cleanliness). During preproduction qualification the manufacturer is permitted to change chemistry and heat treatment details in order to qualify. Once qualified, his chemistry is fixed, but he is permitted reheat treatment of a rejected lot prior to retesting. Thus, the manufacturer is given latitude to decide which steel to use and how to heat treat it.

Whether or not the standard materials specification policy can be used for TRIP steels remains to be demonstrated. In TRIP steels, the resulting properties (particularly strength and tensile ductility) are so dependent on chemistry and processing details that it is not clear whether one can be specified independently of the other. On the other hand, it may be that only the required mechanical properties need to be specified, leaving both chemistry and processing details to the discretion of the manufacturer. Constraints could then be applied to either (or both) chemistry or processing following a preproduction qualification test. Experience to data, however, is insufficient to define the procedures which need to be followed. There remains, therefore, the resolution of some significant metallurgical engineering questions regarding relationships between chemistry, processing, and properties of TRIP steels before suitable materials specifications can be prepared.

SUMMARY AND CONCLUSIONS

A breakthrough has been achieved in high strength steels called TRIP steels. They can be processed to high strength levels with twice the ductility of conventional heat-treated alloy steels. These steels have both the high fracture toughness and high corrosion resistance which are prerequisite to high reliability in

service. TRIP steels are high alloy steels containing 20 to 30 weight percent of alloying elements of which the strategic elements nickel and chromium constitute major amounts. Special warm working is essential to obtain true TRIP steels, and the resulting properties are highly anisotropic and uniquely dependent on chemistry and processing details. TRIP steels can be produced commercially in strip, rod, wire, tubular, and simple forged shapes, but not in plate and sheet form. There is hope that a composition can be found which will permit use of a thermal cycling process in lieu of warm working to high strength, and thus permit use of all commercial metal forming equipment for TRIP steel processing. Because of the unique properties of TRIP steels which minimize risk of brittle fractures in service at low ambient temperatures, selected use in Army hardware will be very cost effective in spite of the relatively high steel cost due to high alloy content. TRIP steels will perform well in both high and low ambient temperature service environments but their properties are lost by heating to several hundred degrees Fahrenheit, thus negating their superiority over conventional steels in elevated temperature environments. Due to the unique properties of TRIP steels and the fact that small changes in composition and/or processing detail may cause large changes in resultant properties, the controls, test, and procedures needed for quality assurance provisions in specifications documents have yet to be defined. Nevertheless, the great potential for these steels in selected hardware components, where they will effect a quantum jump in reliability, is ample justification for expedited research and materials engineering activity leading to their commercial availability.

RECOMMENDATIONS

In order to expedite the development of TRIP steels to the point where MIL specifications can be finalized and the steels utilized for cost-effective benefit on Army hardware, the following RDT&E is recommended.

1. Physical Metallurgy (6.1 or 6.2 Funding)

A basic effort is needed to evolve steel compositions which can be made to TRIP by thermal cycling techniques. This will most probably concentrate on the transformation behavior of reverted austenite in high manganese steels. Additionally, continued effort is warranted to determine composition and processing factors which further enhance strength and ductility over the best properties contained in Figure 1.

2. Materials Engineering (6.2 Funding)

To permit quantitative estimates of Army benefit and to provide a basis for recommending use of TRIP steels in specific components, the following are needed:

a. For the current TRIP steel compositions, determine the permissible variations in TRIP processing which do not affect properties deleteriously.

b. Characterize the engineering properties of TRIP steels to the point where they can be incorporated in handbooks.

c. Determine and quantify the effects of severe military use environments on the engineering properties of TRIP steels.

d. Develop novel test methods as needed to permit meaningful quality assurance testing.

3. Prototype Demonstration (6.3 Funding)

After significant progress in 2 above has been accomplished, a hardware component prototype should be developed for experimental test purposes. The selection should be one where significant benefit can be demonstrated, and the preparation of standardization documents should proceed concurrently with this effort.

Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978, 13 pp, illus-table

AD________________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978, 13 pp, illus-table

AD________________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978, 13 pp, illus-table

AD________________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978, 13 pp, illus-table

AD________________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY
HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978,
13 pp, illus-table

AD_______________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY
HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978,
13 pp, illus-table

AD_______________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY
HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978,
13 pp, illus-table

AD_______________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.

Army Materials and Mechanics Research Center,
Watertown, Massachusetts 02172
TRIP STEELS PROMISE HIGH RELIABILITY
HARDWARE - Kenneth H. Abbott

Monograph Series AMMRC MS 78-2, February 1978,
13 pp, illus-table

AD_______________

UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

TRIP steels
High strength steels
Alloying

Based on a review of the properties of typical TRIP steels, a discussion is presented of possible Army applications for this new material. Problems related to component fabrication and specification controls are presented, and a brief outline of a recommended R&D program is included.